New MiniBooNE Results

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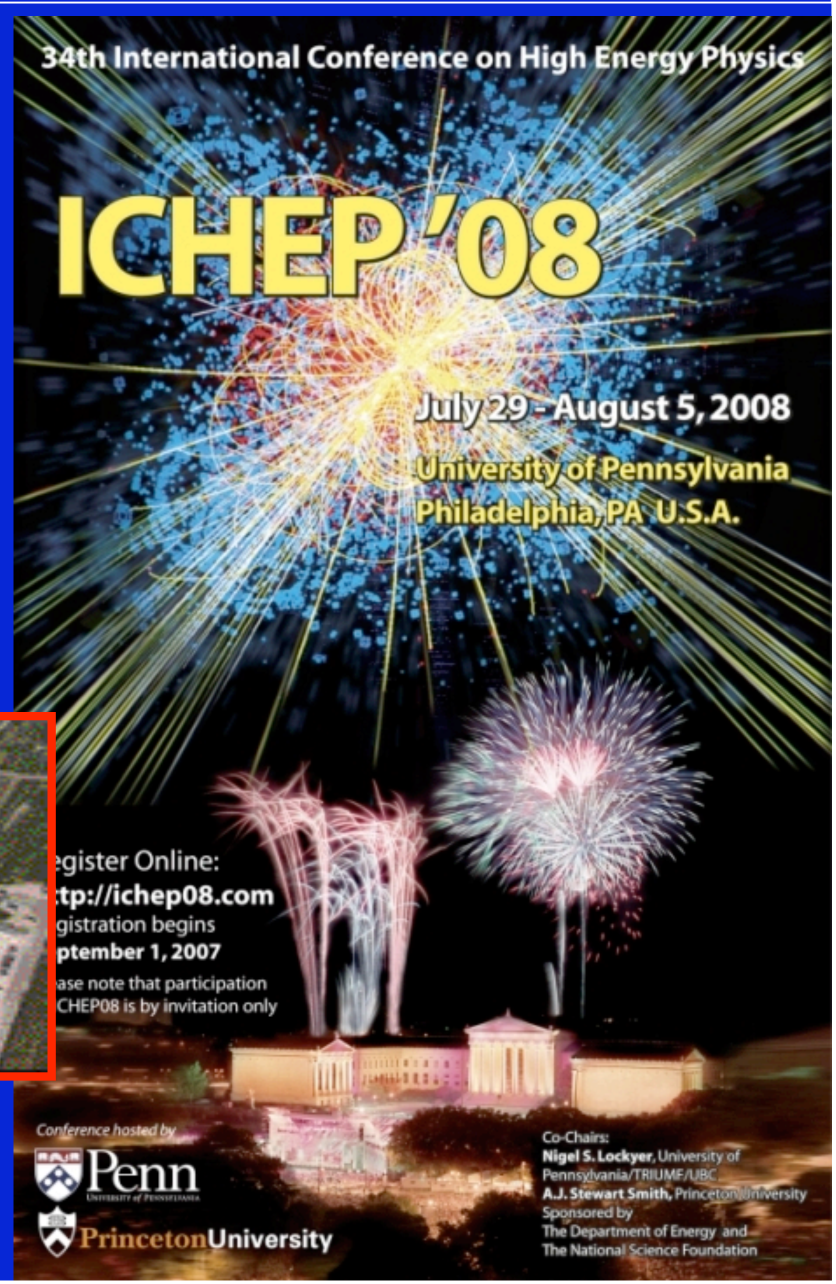
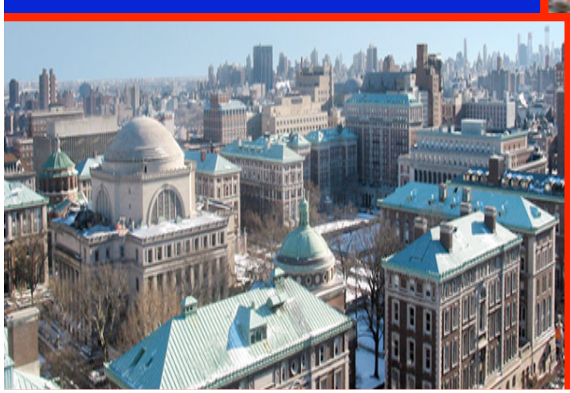




Outline

MiniBooNE Motivation and Description

MiniBooNE's First Oscillation Results

Low Energy Electron Candidate Excess

MiniBooNE's New Results

Results from NuMI at MiniBooNE

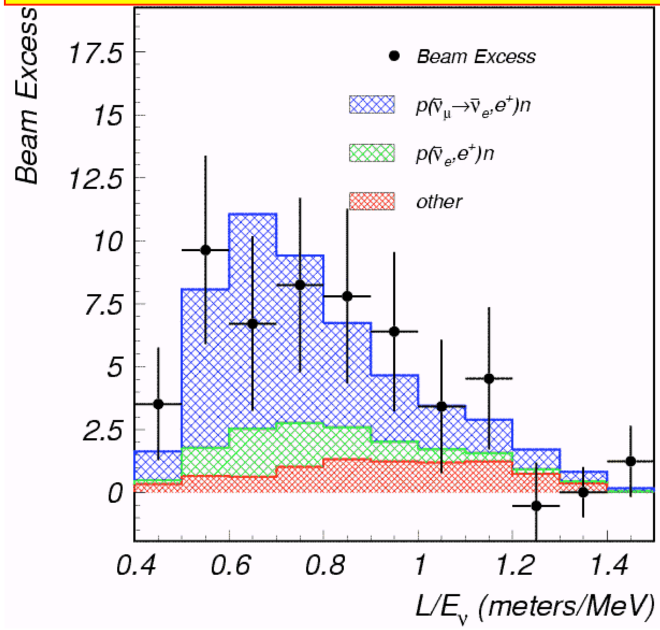
Anti-neutrinos at MiniBooNE

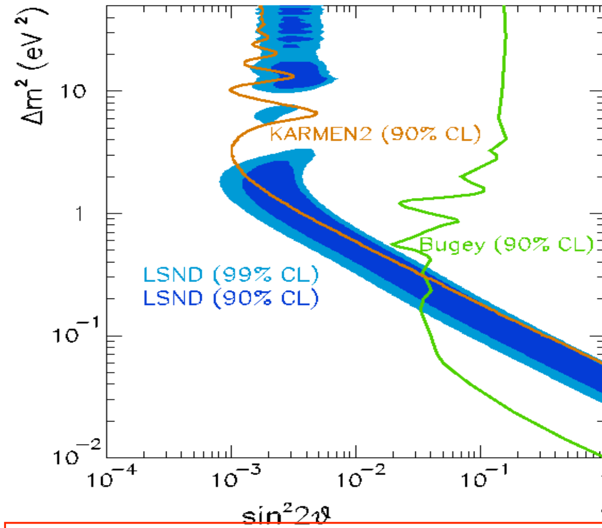
Cross-sections at MiniBooNE

Summary

MiniBooNE Experiment Motivation and Description

MiniBooNE: Motivated by Positive LSND Result

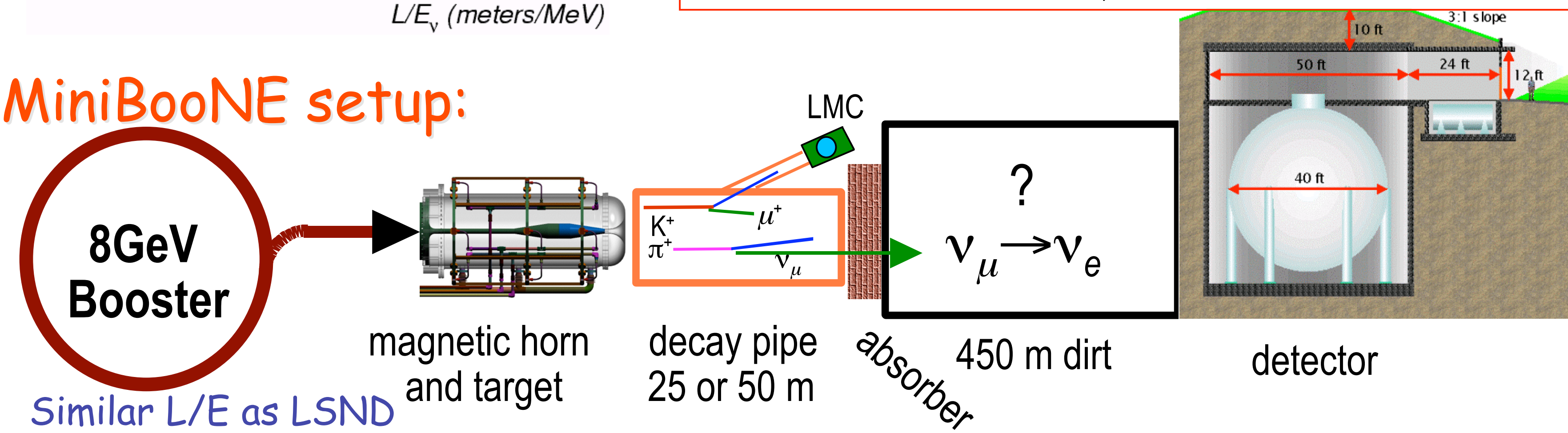




LSND observed a (~3.8σ) excess of $\bar{\nu}_e$ events in a pure $\bar{\nu}_\mu$ beam:
87.9 ± 22.4 ± 6.0 events

Oscillation Probability: $P(\bar{\nu}_\mu \to \bar{\nu}_e) = (0.264 \pm 0.067 \pm 0.045)\%$

MiniBooNE setup:



Similar L/E as LSND
Baseline: L = 540 meters, ~ x15 LSND
Neutrino Beam Energy: E ~ x(10-20) LSND
Different systematics: event signatures and backgrounds different from LSND
High statistics: ~ x6 LSND
Perform experiment in both neutrino and anti-neutrino modes.

MiniBooNE

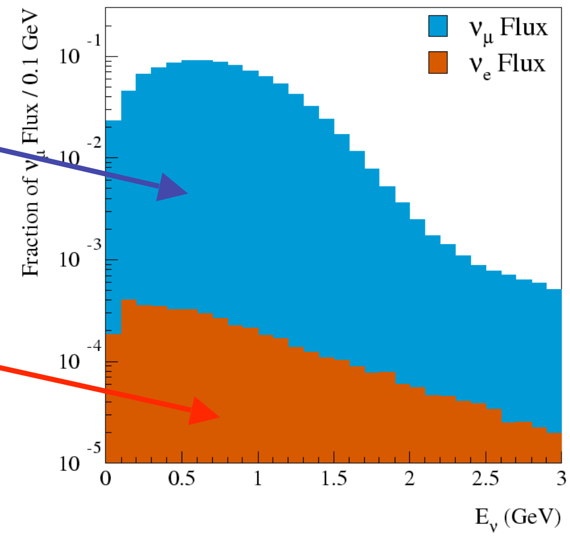
(Booster Neutrino Experiment)

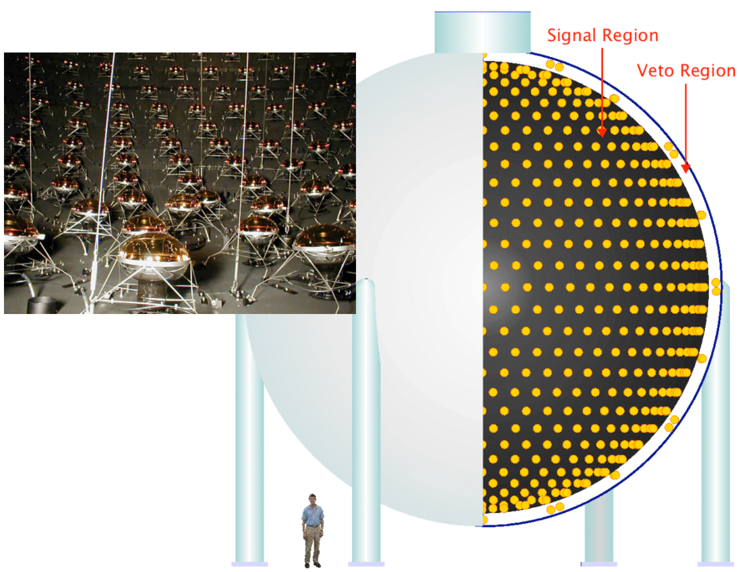
Oscillation Analysis

$\nu_\mu \rightarrow \nu_e$ Oscillation Search

- Main ν_μ flux from $\pi^+ \rightarrow \mu^+ \ \nu_\mu$
- Intrinsic ν_e flux from
  - $\mu^+ \rightarrow \nu_\mu \ e^+ \ \nu_e$
  - $K^+ \rightarrow \pi^0 \ e^+ \ \nu_e$
  - $K^0_L \rightarrow \pi^- \ e^+ \ \nu_e$

$\Rightarrow$ **$\nu_e / \nu_\mu \approx 0.5\%$**



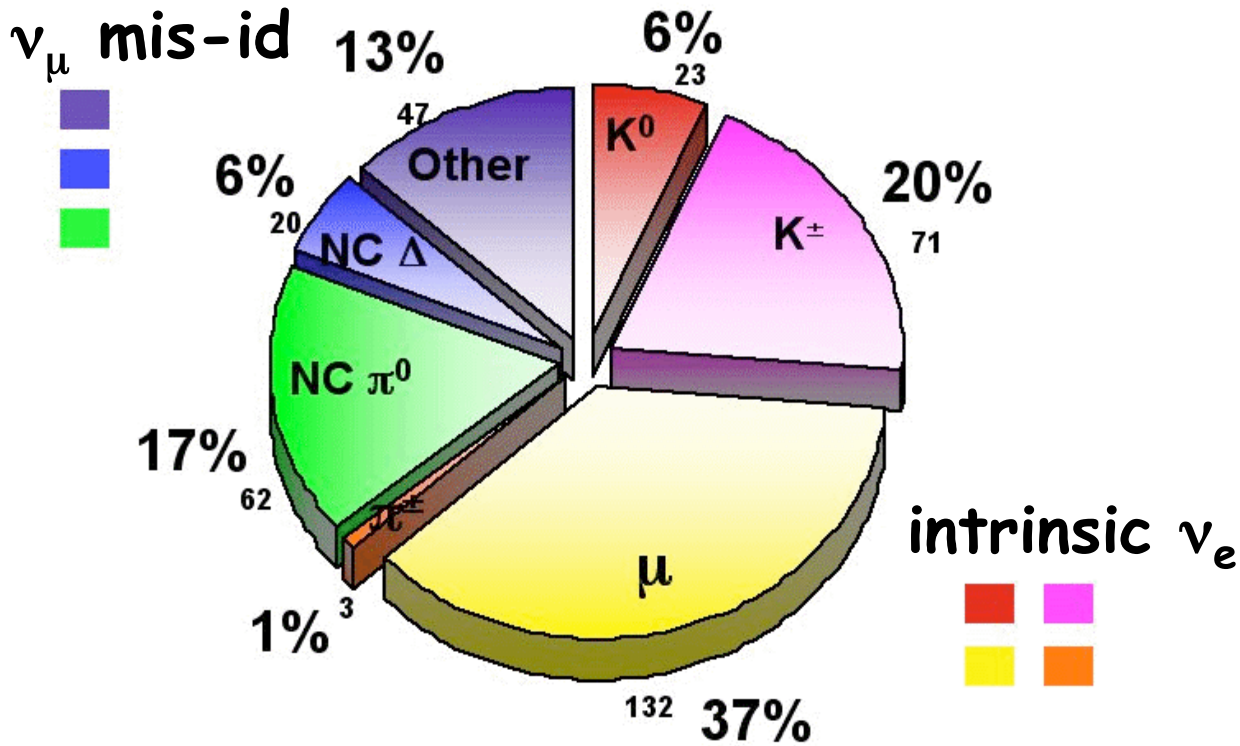


MiniBooNE Detector:
- -12m diameter sphere
- -950000 liters of oil(CH_2)
- -1280 inner PMTs
- -240 veto PMTs

Detector Requirements:
- -Detect and Measure Events: Vertex, E_ν …
- -Separate ν_μ events from ν_e events.

Oscillation Analysis: Expected Background Events

Two main categories of backgrounds: ν_μ mis-ids and intrinsic ν_e



→ Events with ν_e Selection requirements

$475 < E_\nu < 1250$ MeV

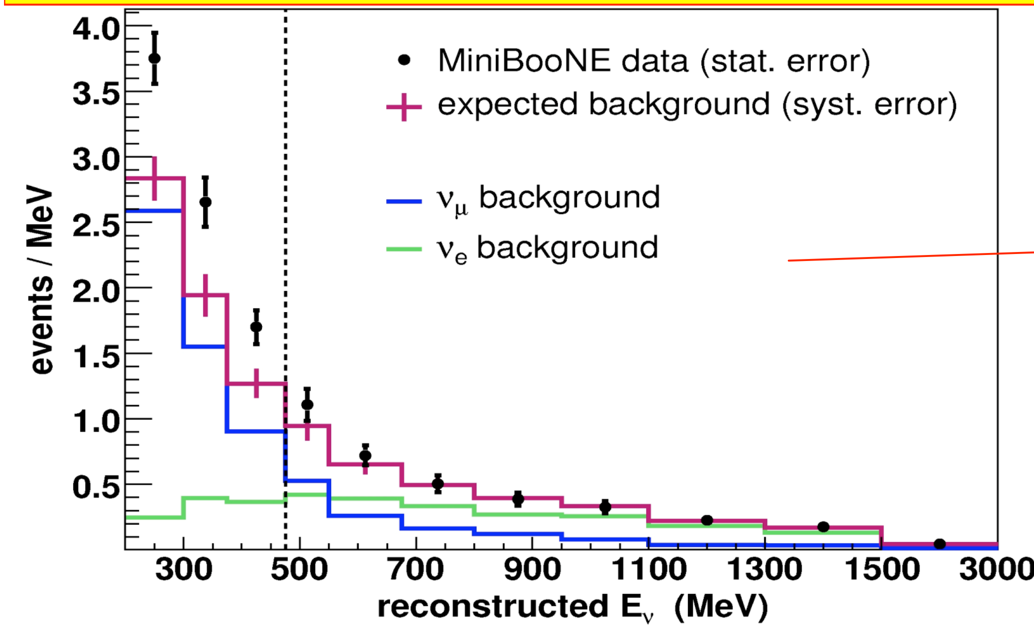
Predicted backgrounds after particle identification:

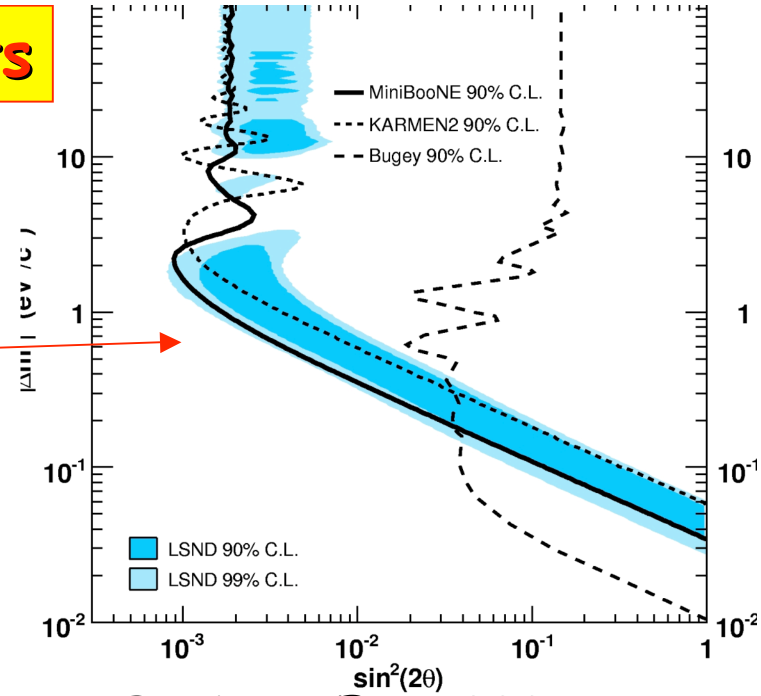
Total Expected Background = 358 events.

Example LSND Osc Signal = 163 events
($\Delta m^2 = 0.4$ eV^2 , $\sin^2 2\theta = 0.017$).

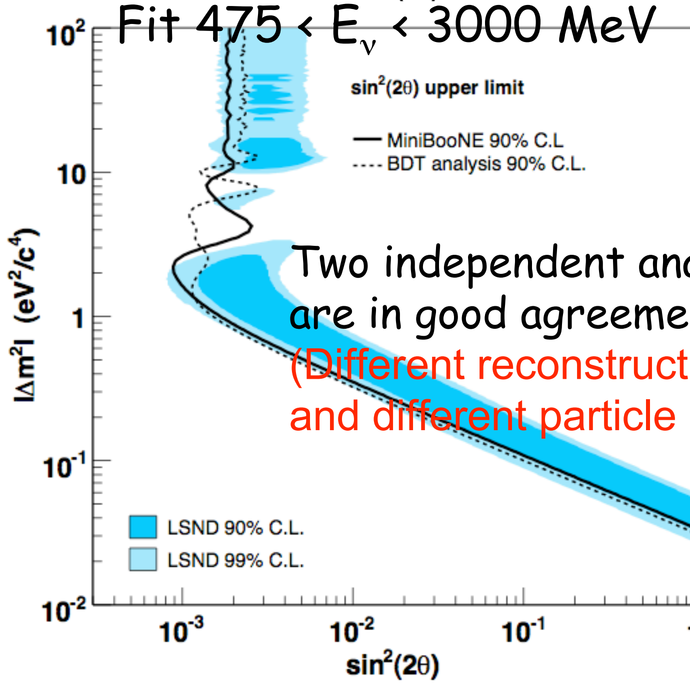
5.6×10^{20} POT in neutrino mode used for the analysis.

(First) Oscillation Analysis: Results





Fit 475 < E_ν < 3000 MeV



Two independent analyses are in good agreement.
(Different reconstructions and different particle id)

Region 475 < E_ν < 1250 MeV
Data: 380 events
Expected: 358±19±35 events
Difference: 0.55 σ

MiniBooNE's first result show no evidence for $\nu_\mu \rightarrow \nu_e$ appearance-only oscillations in the analysis region: simple 2ν oscillation excluded at 98% CL.

Details:

Phys. Rev. Lett. 98, 231801 (2007), arXiv:0704.1500 [hep-ex]

Ten Top Physics Stories for 2007

Physics News Update

The AIP Bulletin of Physics News

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Number 850 #1, December 13 , 2007 by Phil Schewe

Ten Top Physics Stories for 2007

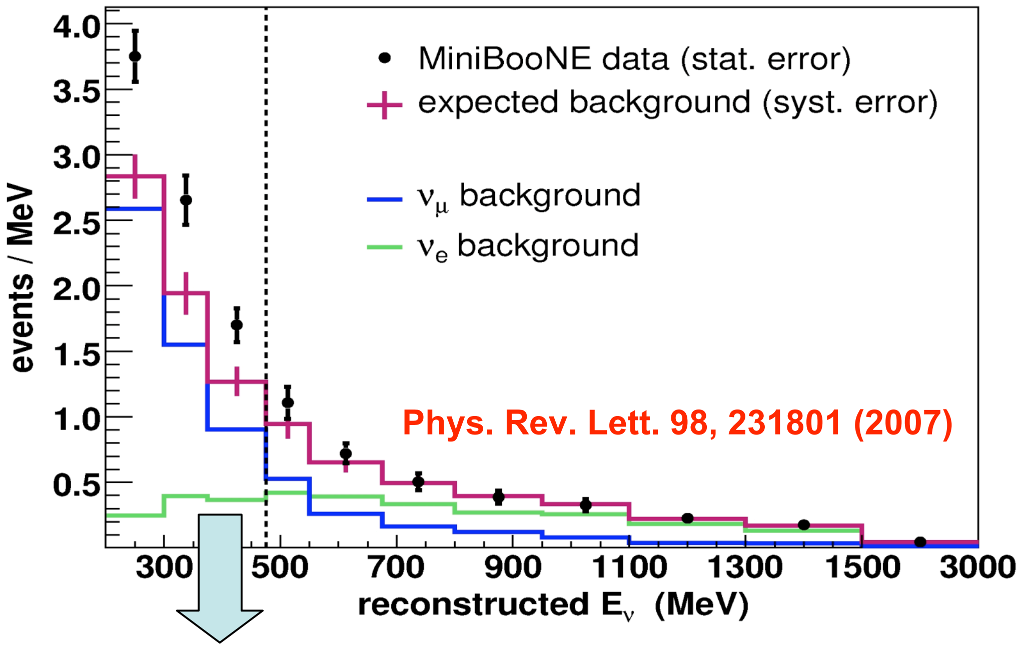
In chronological order during the year:

1. Light, slowed in one Bose Einstein condensate (BEC), is passed on to another BEC (http://www.aip.org/pnu/2007/split/812-1.html);
2. Electron tunneling in real time can be observed with the use of attosecond pulses (http://www.aip.org/pnu/2007/split/818-2.html);
3. Laser cooling of coin-sized object, at least in one dimension (http://www.aip.org/pnu/2007/split/818-1.html);
4. The best test ever of Newton's second law, using a tabletop torsion pendulum (http://www.aip.org/pnu/2007/split/819-1.html);
5. First Gravity Probe B first results, the measurement of the geodetic effect---the warping of spacetime in the vicinity of and caused by Earth-to a precision of 1%, with better precision yet to come (http://www.aip.org/pnu/2007/split/820-2.html).
6. The MiniBooNE experiment at Fermilab solves a neutrino mystery, apparently dismissing the possibility of a fourth species of neutrino (http://www.aip.org/pnu/2007/split/820-1.html);
7. The Tevatron, in its quest to observe the Higgs boson, updated the top quark mass and observed several new types of collision events, such as those in which only a single top quark is made, and those in which a W and Z boson or two Z bosons are made simultaneously (http://www.aip.org/pnu/2007/split/821-1.html);
8. The shortest light pulse, a 130-attosecond burst of extreme ultraviolet light (http://www.aip.org/pnu/2007/split/823-1.html);
9. Based on data recorded at the Auger Observatory, astronomers conclude that the highest energy cosmic rays come from active galactic nuclei (http://www.aip.org/pnu/2007/split/846-1.html);

The MiniBooNE experiment at Fermilab solves a neutrino mystery.

Low Energy Excess

Investigation of observed low-energy excess



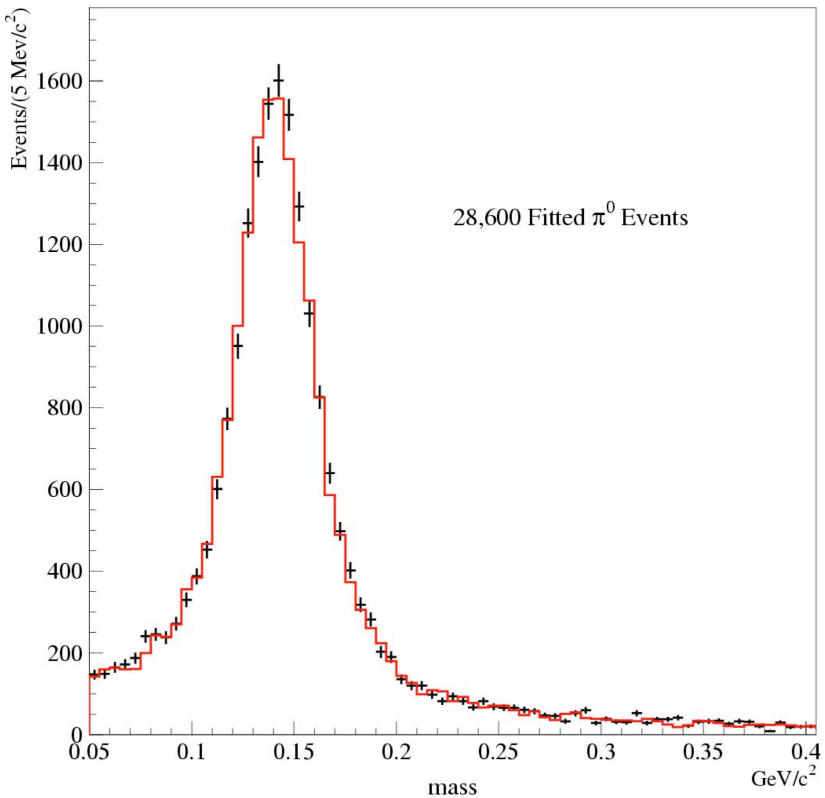
-Good description of data at high energy.
-Excess of data events at low energy.

What is the nature of the excess?

- Possible detector anomalies or reconstruction problems?
- Incorrect estimation of the background?
- New sources of background?
- New physics including exotic oscillation scenarios?

Any of these backgrounds or signals could have an important impact on other future oscillation experiments.

Measuring π^0 and constraining misIDs from π^0



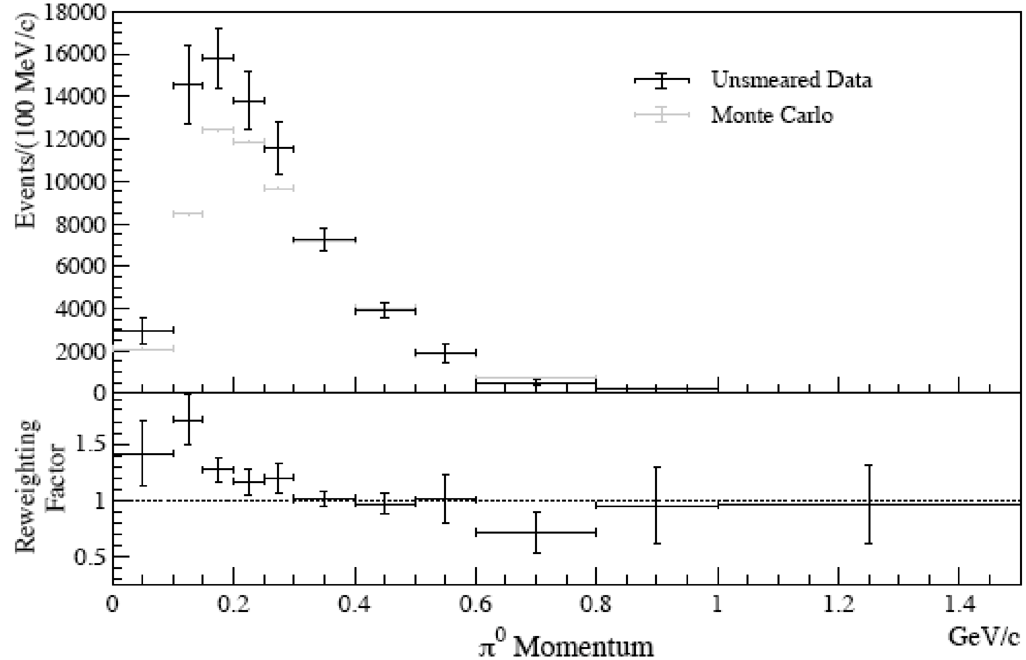


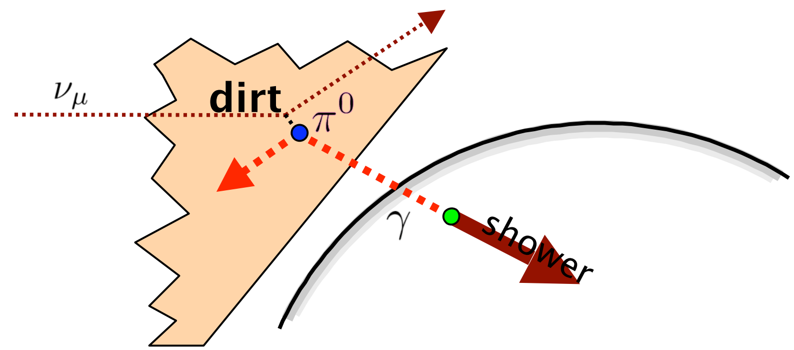
Fig. 1. Top: Results of the π^0 unsmearing in bins of momentum. The dark points show the unsmeared data π^0 momentum distribution and the light points show the uncorrected MC π^0 momentum distribution. The unsmeared data error bars contain all sources of error propagated through the unsmearing, while the MC error bars are from finite MC statistics. Bottom: The reweighing function, formed by taking ratio of the two points above (data/MC).

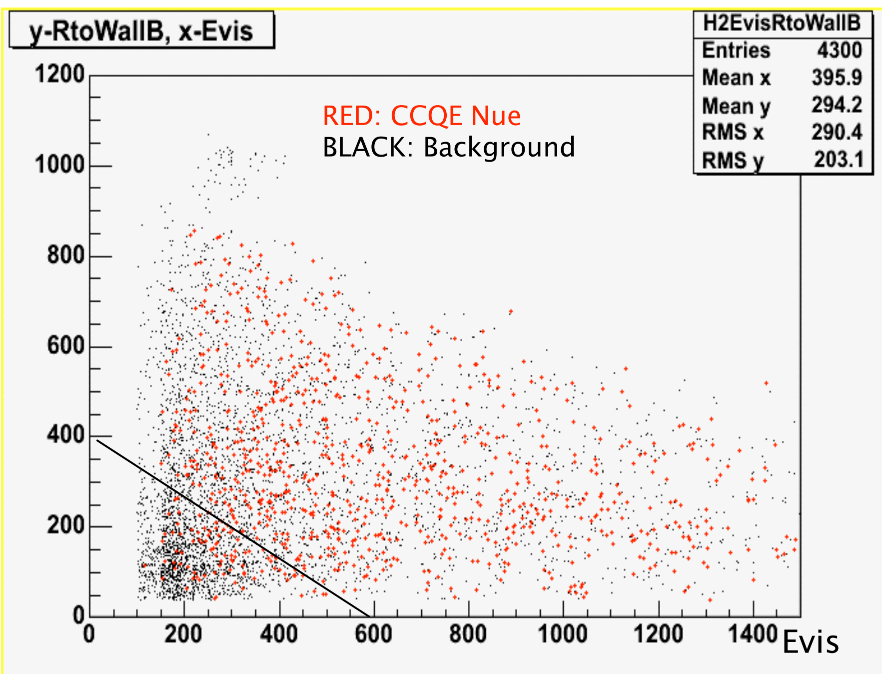
π^0 rate measured to a few % .
Critical input to oscillation analysis: without constraint π^0 errors would be ~ 20%

Details Phys.Lett.B664, 41(2008)

Is the dirt responsible for the low-energy excess?

In low energy region there is a significant background from neutrino interactions in the region outside the tank ("dirt").





Dirt events tend to be at large radius, heading inward

Add a new cut on "Distance to Wall backward" to reduce these.

Has significant effect below 475 MeV to signal/background ratio

- Big reduction in dirt
- Some reduction of π^0s
- Small effect on ν_es

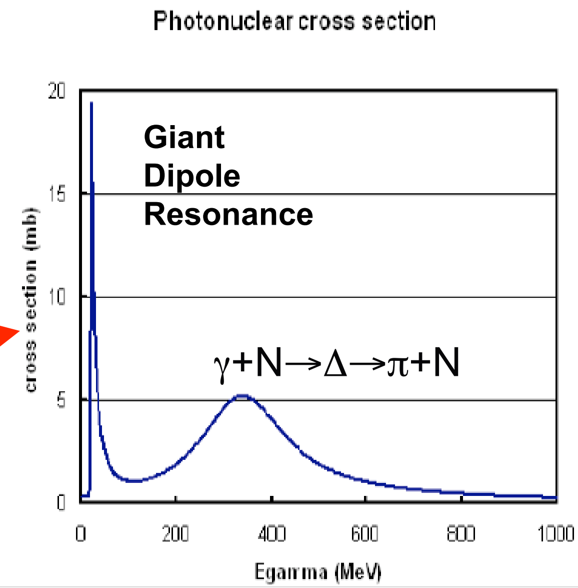
Has almost no effect above 475 MeV

Photonuclear absorption of π^0 photon

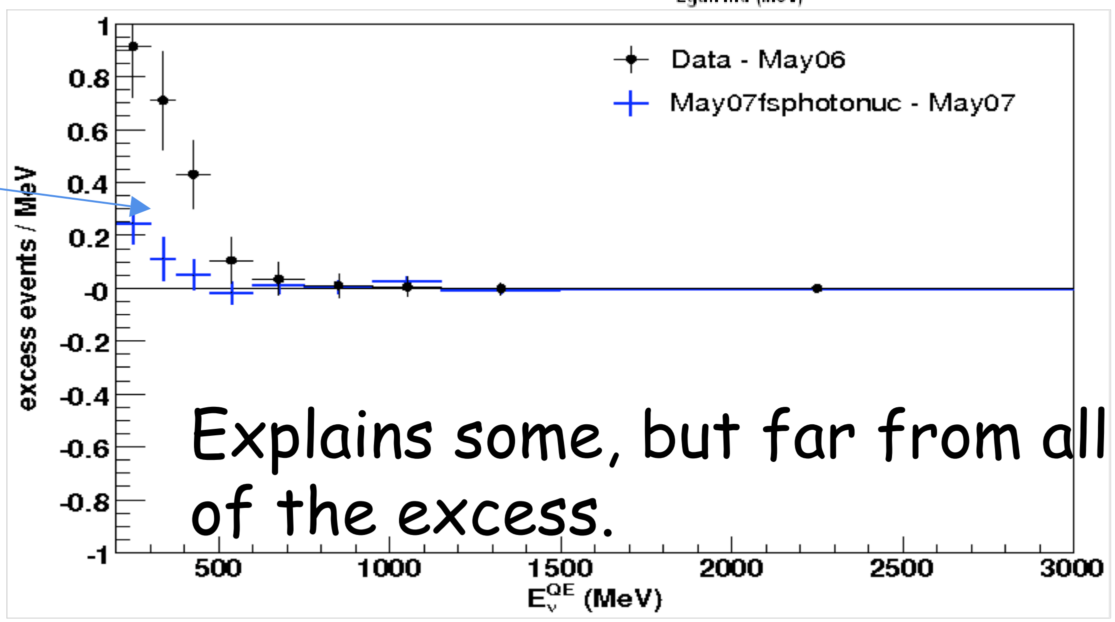
Since MiniBooNE cannot tell an electron from a single gamma, any process that leads to a single gamma in the final state will be a background

Processes that remove ("absorb") one of the gammas from a ν_μ-induced NC $\pi^0 \rightarrow \gamma\gamma$

- photonuclear absorption



Adding this into the MC increases π^0 background by about 20%



Explains some, but far from all of the excess.

New Results

Improvements in the Analysis

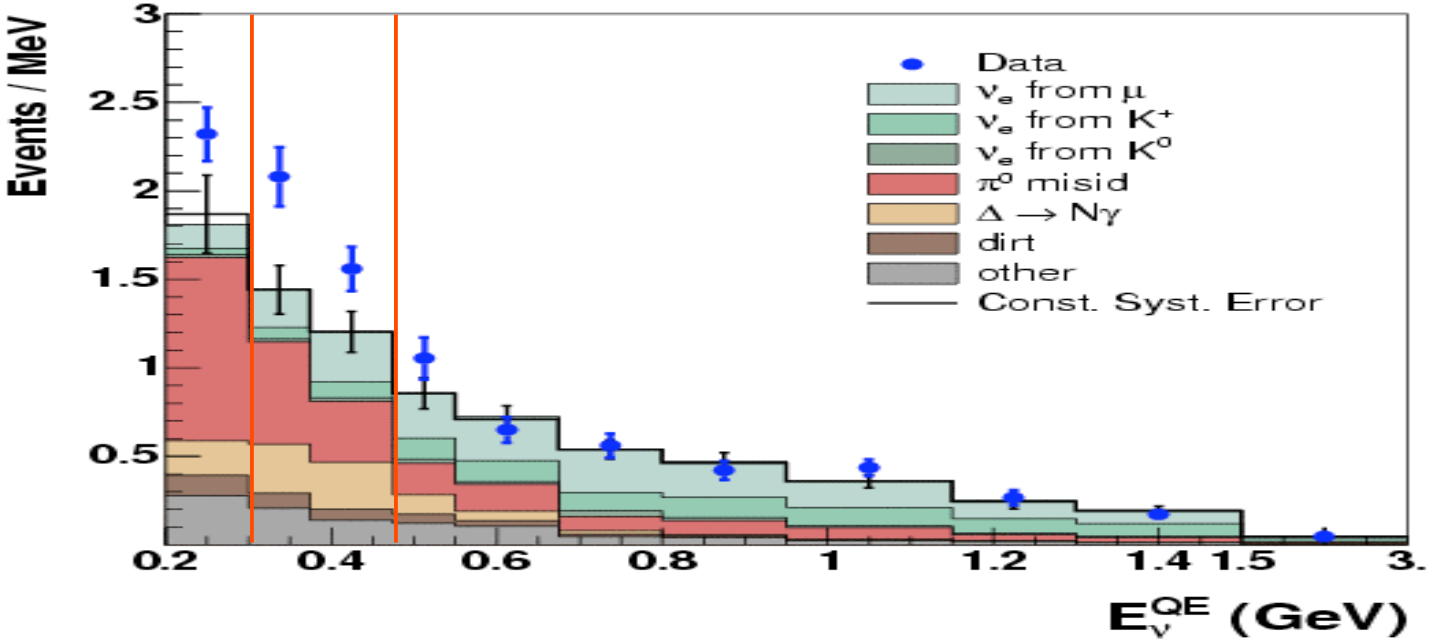
- Improved π^0 (coherent) production incorporated.
- Rechecked various background cross-section and rates ($\Delta \rightarrow N\gamma$,etc.)
- Photo-nuclear interactions included.
- Improved estimate of the background from external events ("dirt") performed.
- More efficient rejection of the "dirt" events applied.
- Analysis threshold lowered to 200 MeV.
- Improved estimates of systematic errors (i.e. flux).

- Additional data set included in new results:

  Old analysis: 5.58×10^{20} protons on target.

  New analysis: 6.46×10^{20} protons on target.

New Results



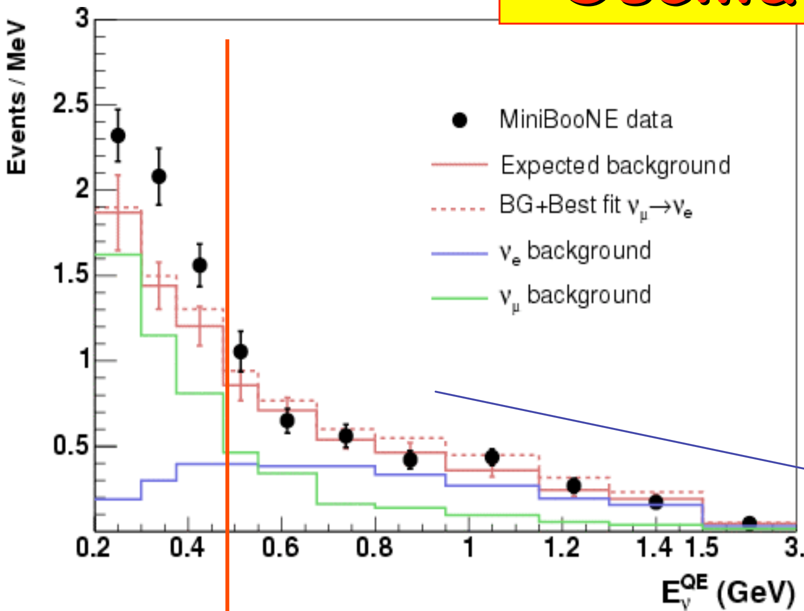
MC systematics includes data statistics.

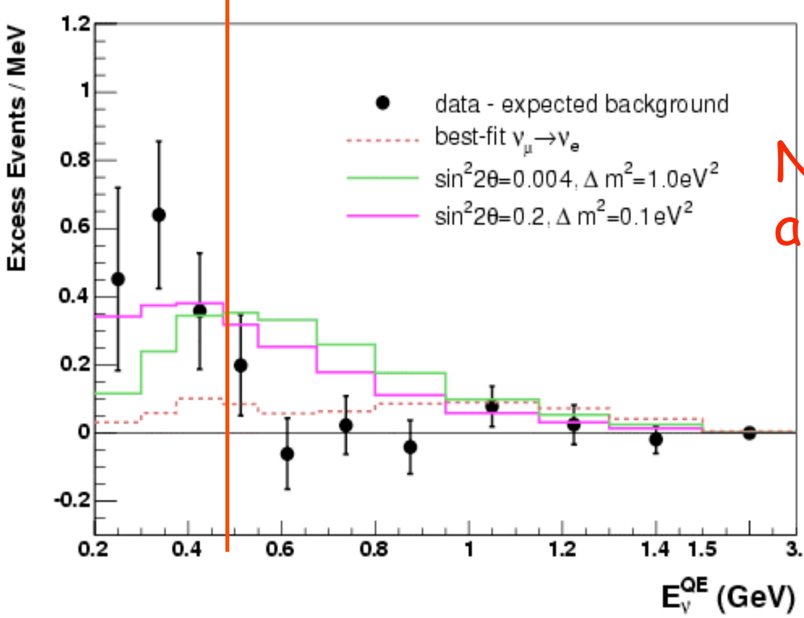
E_ν [MeV]	200-300	300-475	475-1250
total background	186.8±26	228.3±24.5	385.9±35.7
ν_e intrinsic	18.8	61.7	248.9
ν_μ induced	168	166.6	137
NC π^0	103.5	77.8	71.2
NC $\Delta \rightarrow N\gamma$	19.5	47.5	19.4
Dirt	11.5	12.3	11.5
other	33.5	29	34.9
Data	232	312	408
Data-MC	45.2±26	83.7±24.5	22.1±35.7
Significance	1.7σ	3.4σ	0.6σ

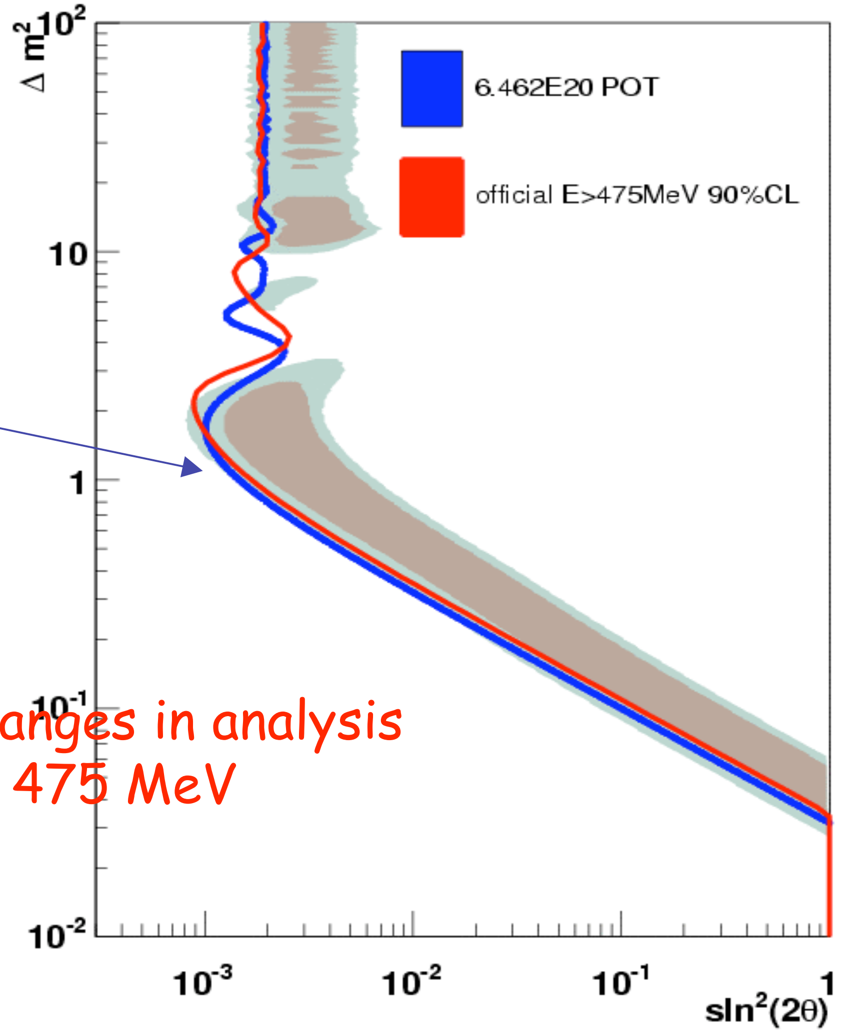
The excess at low energy remains significant!

This will be published soon.

Oscillation Fit Check







No changes in analysis above 475 MeV

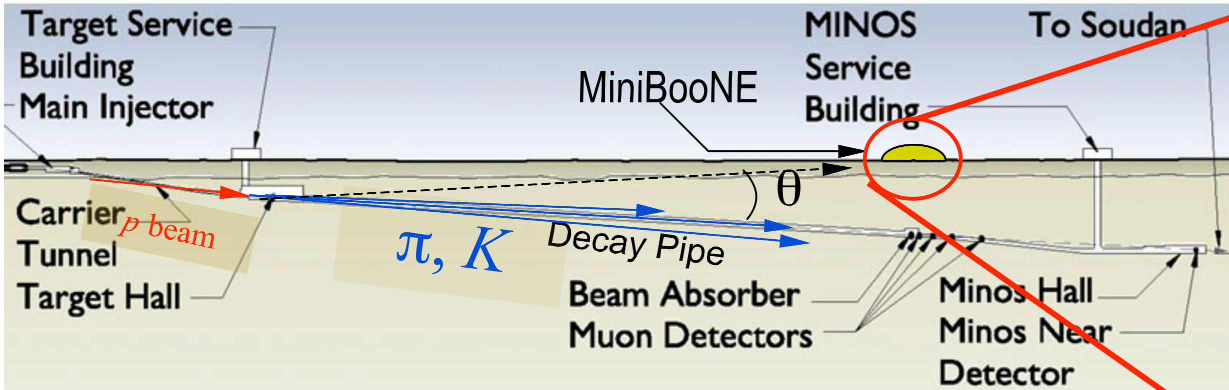
	E_ν>475 MeV	E_ν>200 MeV
Null fit χ^2 (prob.):	9.1(91%)	22(28%)
Best fit χ^2 (prob.):	7.2(93%)	18.3(37%)

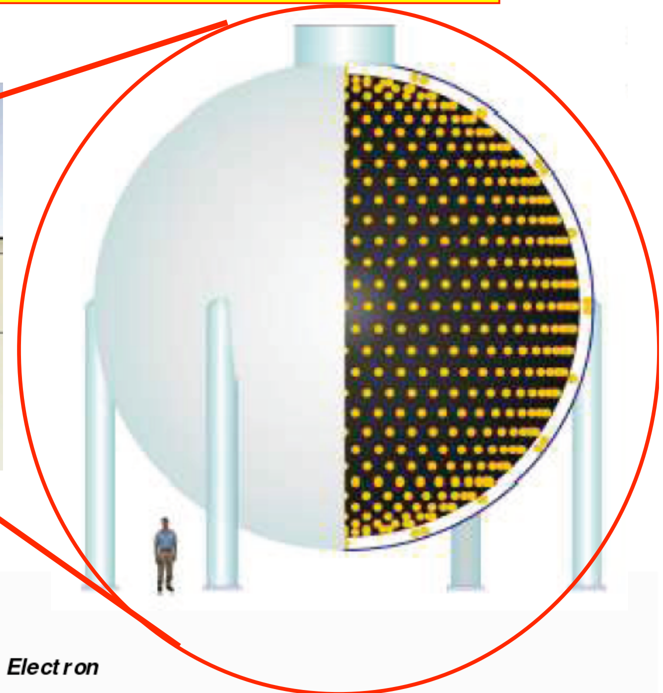
Clearly, more evidence is needed to understand the excess…

Events from NuMI beamline

(collected and analyzed in Collaboration with MINOS)

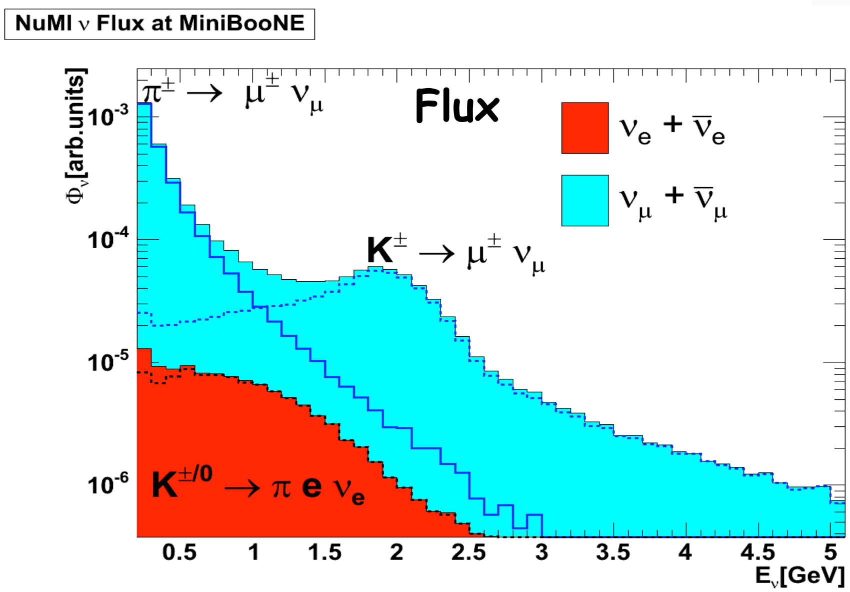
Events from NuMI detected at MiniBooNE

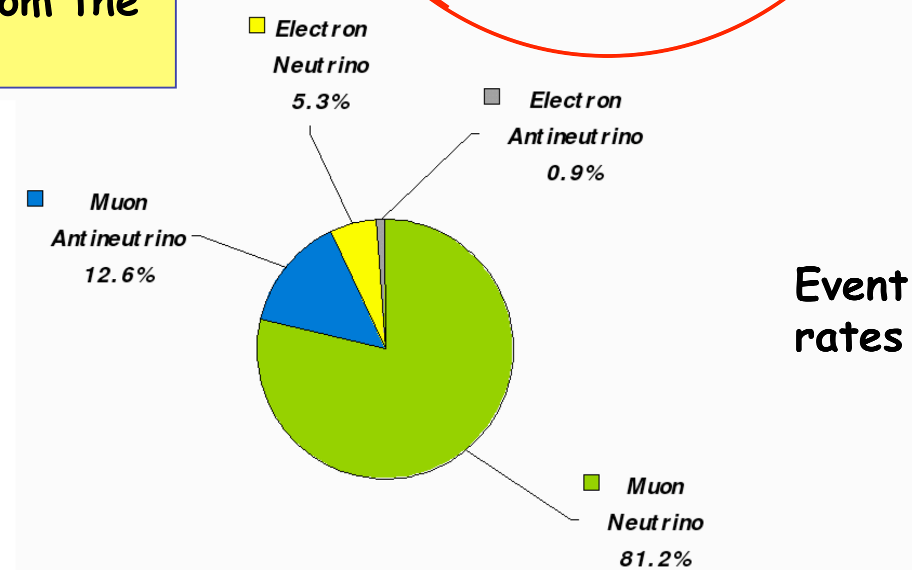




MiniBooNE detector is 745 meters downstream of NuMI target.

MiniBooNE detector is 110 mrad off-axis from the target along NuMI decay pipe.

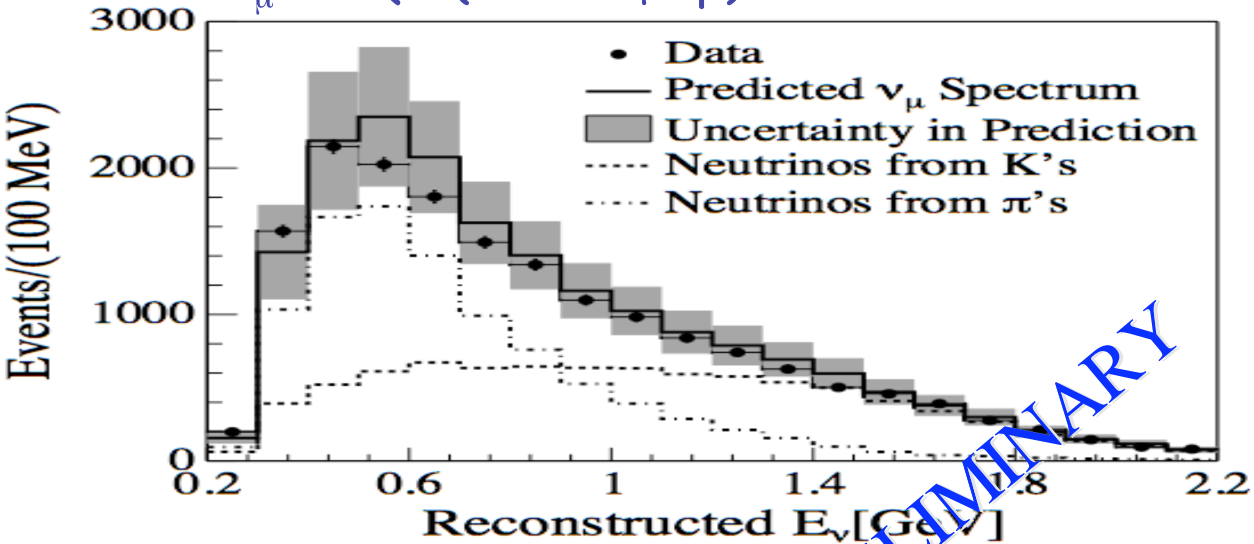




NuMI event composition at MB
ν_μ-81%, ν_e-5%, $\bar{\nu}_\mu$-13%, $\bar{\nu}_e$-1%

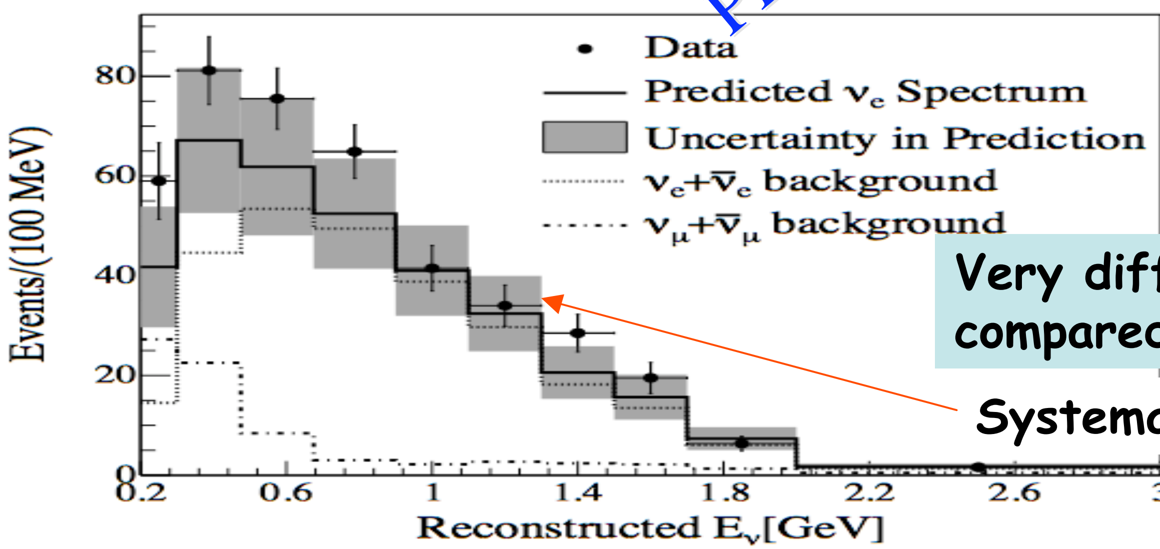
ν_μ CCQE and ν_e CCQE samples from NuMI

ν_μ CCQE (ν+n $\rightarrow$ μ+p)



Because of the good data/MC agreement in ν_μ flux and because the ν_μ and ν_e share same parents the beam MC can now be used to predict:
ν_e rate and mis-id backgrounds
for a ν_e analysis.

ν_e CCQE (ν+n $\rightarrow$ e+p)



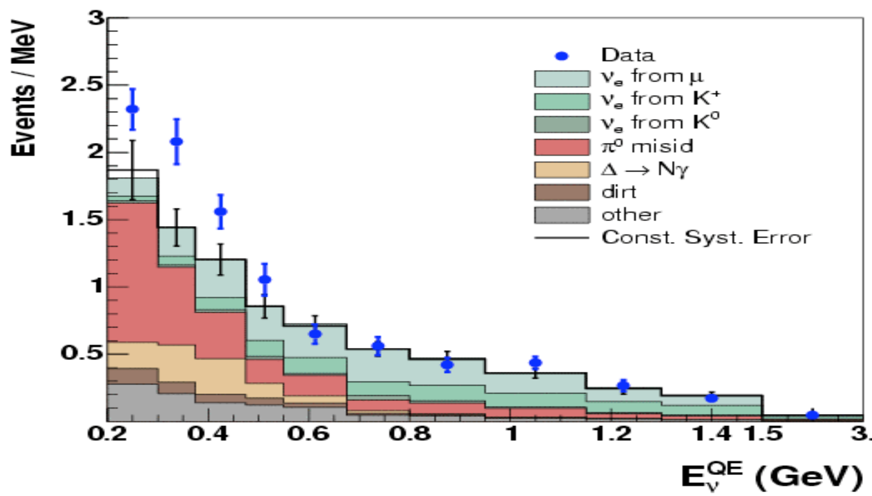
Very different backgrounds compared to MB (Kaons vs Pions)!

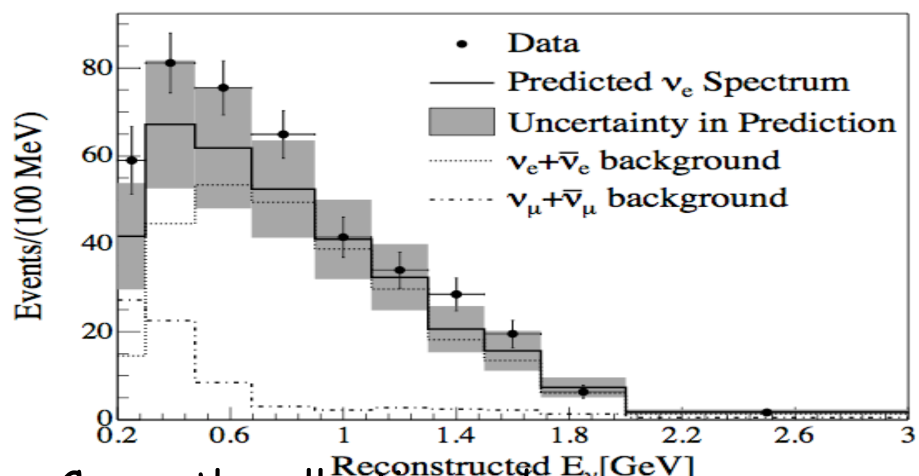
Systematics not yet constrained!

NuMI vs Booster Beam at MiniBooNE

Recall:
1) Distance to MiniBooNE:
L (from NuMI source) ≈ 1.4 L (from Booster beam source).

2) Neutrino Oscillation depends on L and E through L/E ratio.
Therefore, if an anomaly seen at some E in Booster beam data is due to oscillation it should appear at 1.4E in the NuMI beam data at MiniBooNE.





Currently collecting and analyzing more data from NuMI beamline!

Anti-neutrinos at MiniBooNE

MiniBooNE Anti-neutrino Run

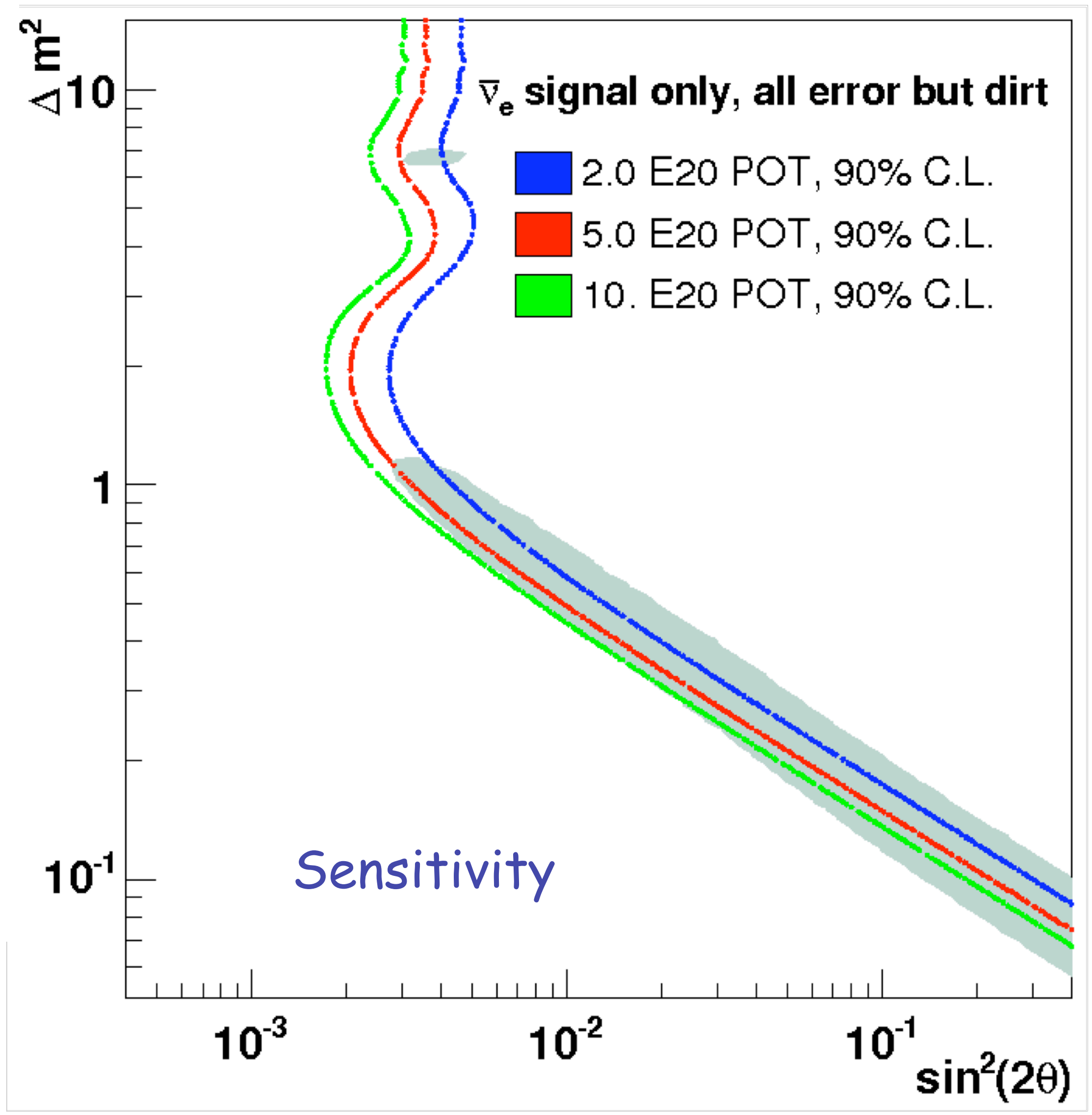
MiniBooNE is currently taking data in anti-neutrino mode.

In November 07 Physics Advisory Committee (Fermilab) recommended MiniBooNE run to get to a total of 5×10^{20} POT in anti neutrino mode.

Provides direct check of LSND result.

Provides additional data set for low energy excess study.

Collected ~3.3×10^{20} POT so far.
Oscillation data set "blinded".



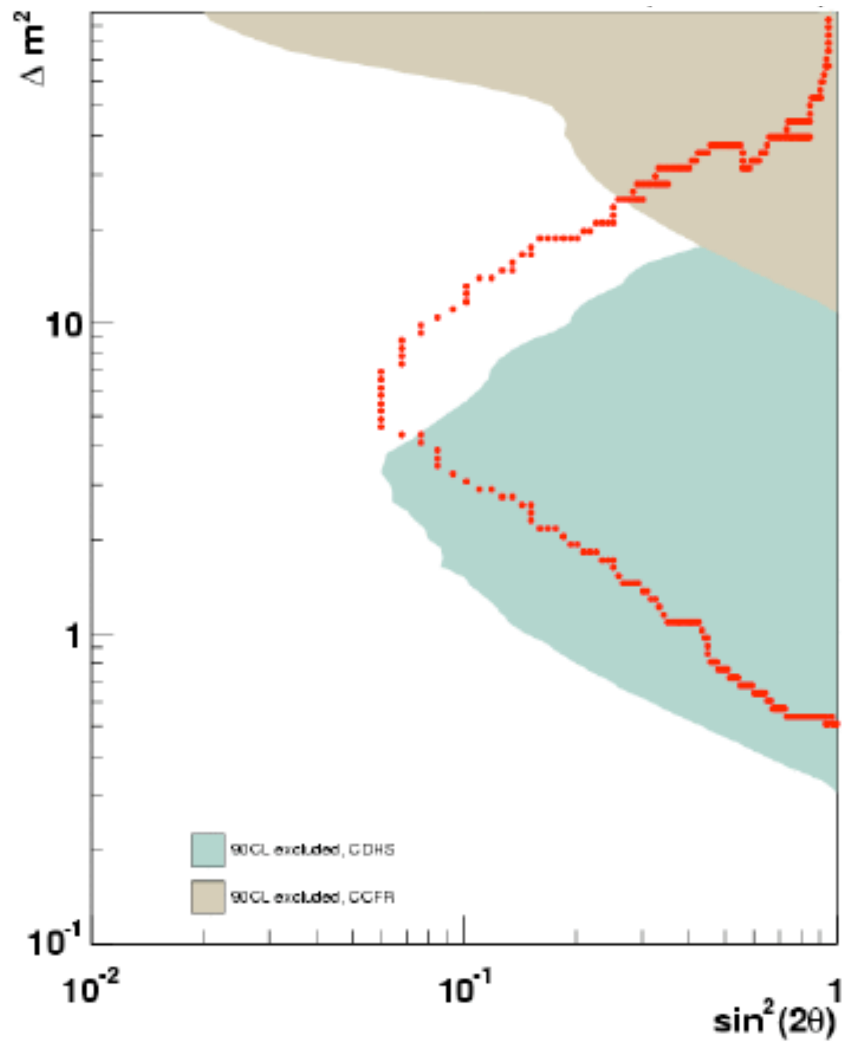
ν_μ Disappearance at MiniBooNE

ν_μ Disappearance: Ongoing Analysis

- MiniBooNE only 90% CL sensitivity

- CDHS CCFR 90% CL

When we use SciBooNE as a near detector, we will be able to improve this sensitivity by reducing flux and cross section uncertainties



To hear about SciBooNE: talk by K. Hiraide.

Cross-sections at MiniBooNE

MiniBooNE Cross-section Results

- ν_μ QE M_A, κ results: Phys. Rev. Lett. **100**, 032301 (2008)
- NC coherent π^0 production in ν mode: Phys. Lett. **B664**, 41 (2008)

- NC coherent π^0 production in $\bar{\nu}$ mode, V. Nguyen poster at ICHEP08
- CC π^+/QE cross section ratio, S. Linden poster

coming soon:

- ν_μ QE differential cross sections
- NC elastic cross section
- CC π^+ cross sections
- CC π^0 production
- QE results in $\bar{\nu}$ mode

Summary

-MiniBooNE first result show no evidence for $\nu_\mu \rightarrow \nu_e$ appearance-only oscillations in the analysis region above 475 MeV.

-However, at low energy (<475MeV) excess observed; thoroughly checked and confirmed with new analysis and additional data set.

-We observed and analyzed the neutrino events from NuMI beamline at MiniBooNE.
-MiniBooNE is collecting more data from NuMI beamline.
-We are currently performing an analysis where ν_e CCQE sample systematics constrained by ν_μ CCQE sample: common systematics cancels.

-MiniBooNE is currently taking data in anti-neutrino mode.
-Provides direct check of LSND result.
-Provides additional data set (with NuMI) for low energy excess study.

-ν_μ disappearance analysis is underway.

-New cross-section results coming soon.

-Interesting ideas to explain the excess appeared in community.

Backup Slides

Particle Identification

Čerenkov rings provide primary means of identifying products of ν interactions in the detector

Muon

ν_μ n → μ^- p

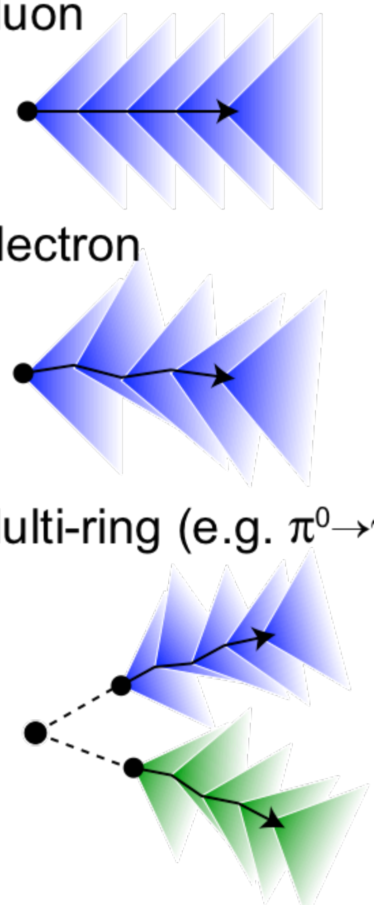
Electron

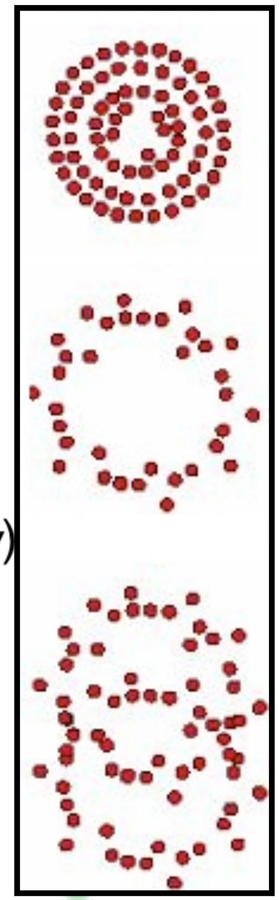
ν_e n → e^- p

Multi-ring (e.g. $\pi^0 \to \gamma\gamma$)

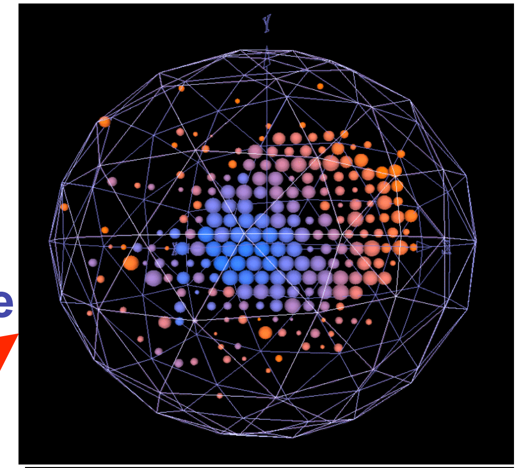
ν_μ p → ν_μ p π^0

n n

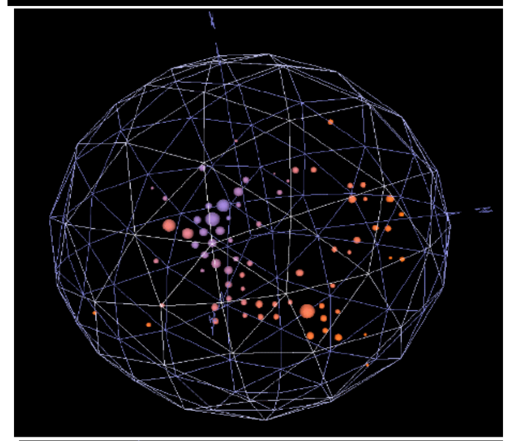




beam μ candidate

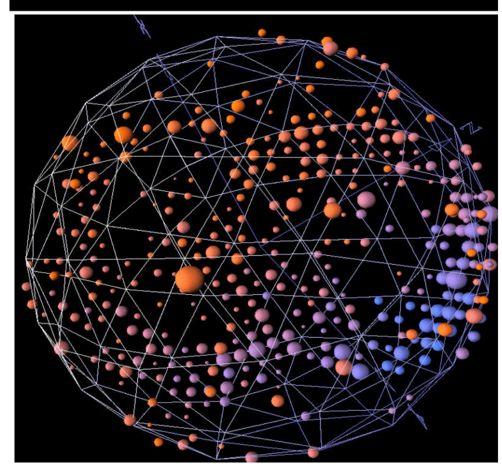


μ-decay e^- candidate



beam π^0 candidate

$\pi^0 \longrightarrow \gamma\gamma$



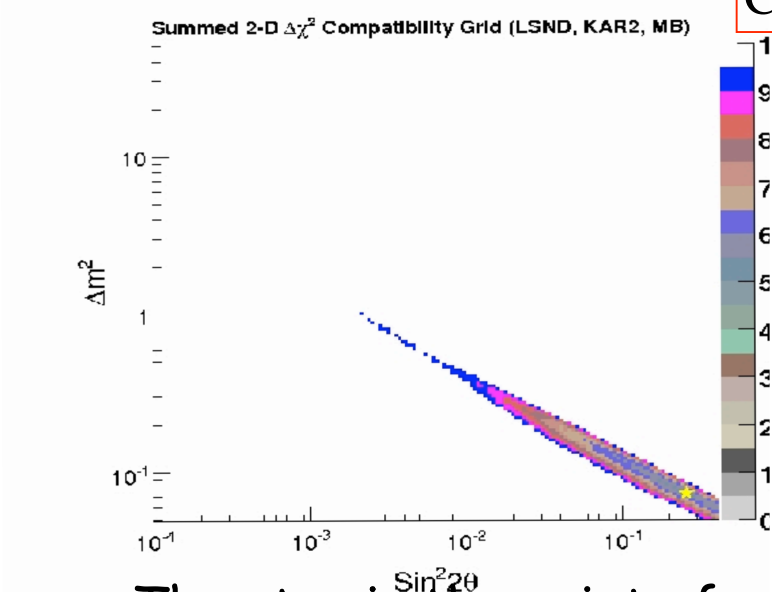
Global Data Analysis

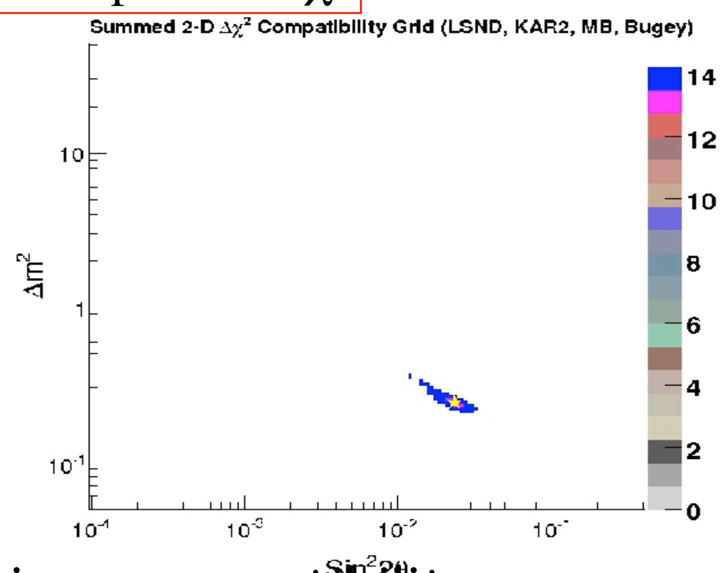
Combine results from several experiments: LSND, MiniBooNE, Karmen and Bugey.

Get allowed regions

Where would oscillation parameters Δm^2 , $\sin^2 2\theta$ lie assuming that all experimental results come from the same underlying $\nu_\mu \rightarrow \nu_e$ oscillation hypothesis?

Colors represent $\Delta\chi^2$

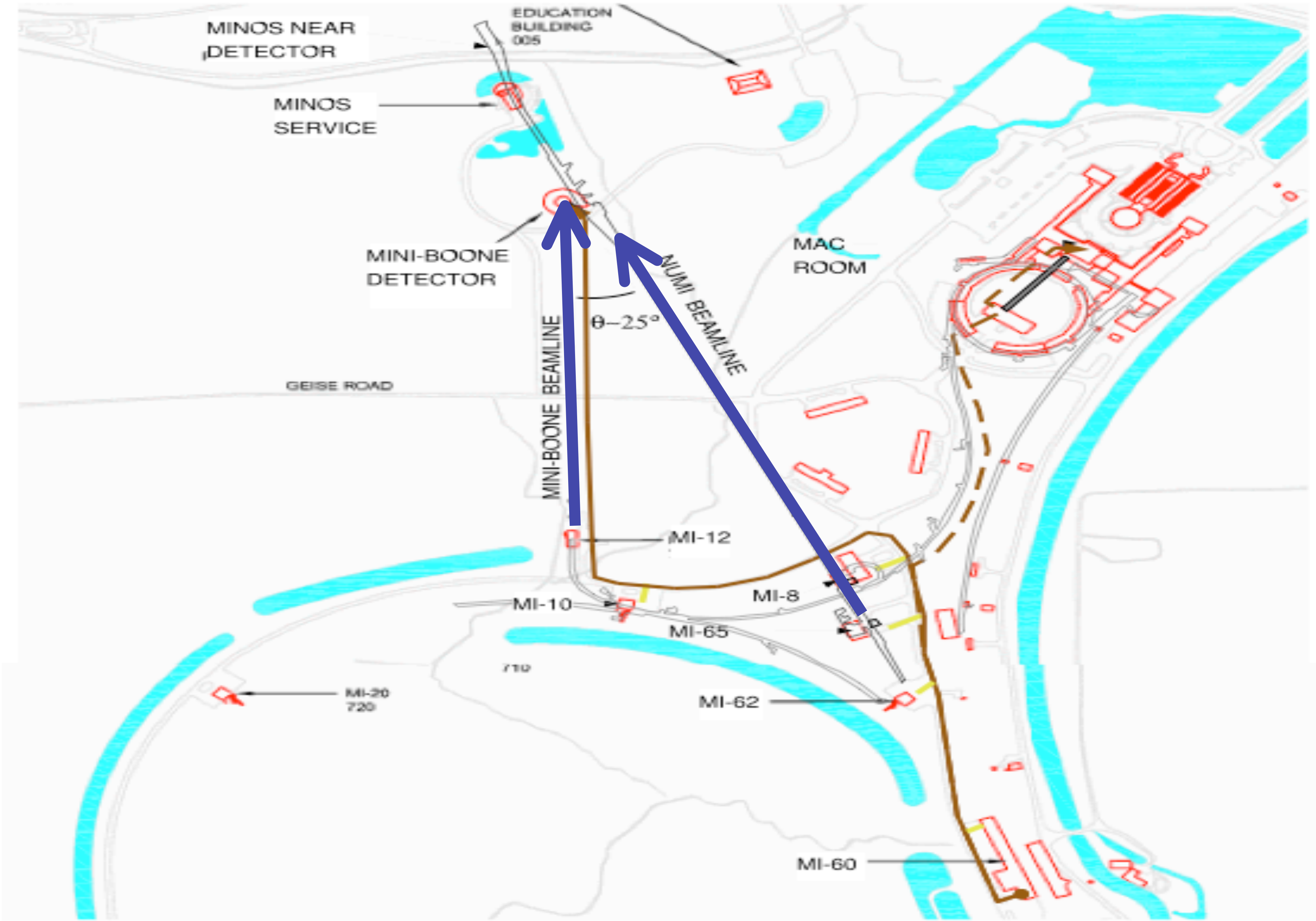




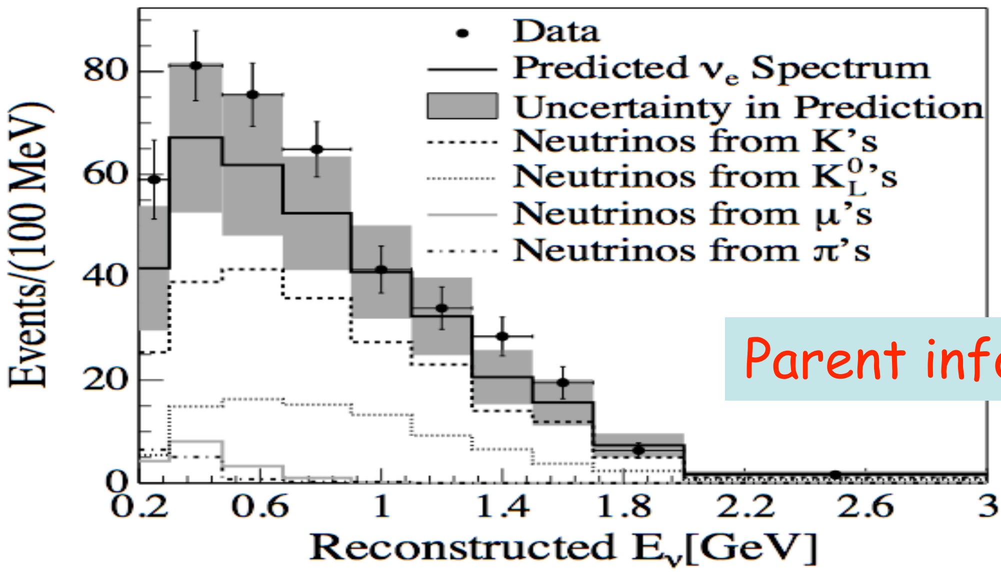
The star is the point of maximum compatibility

LSND, KARMEN2, MB + BUGEY Details arXiv:0805.1764 [hep-ex]

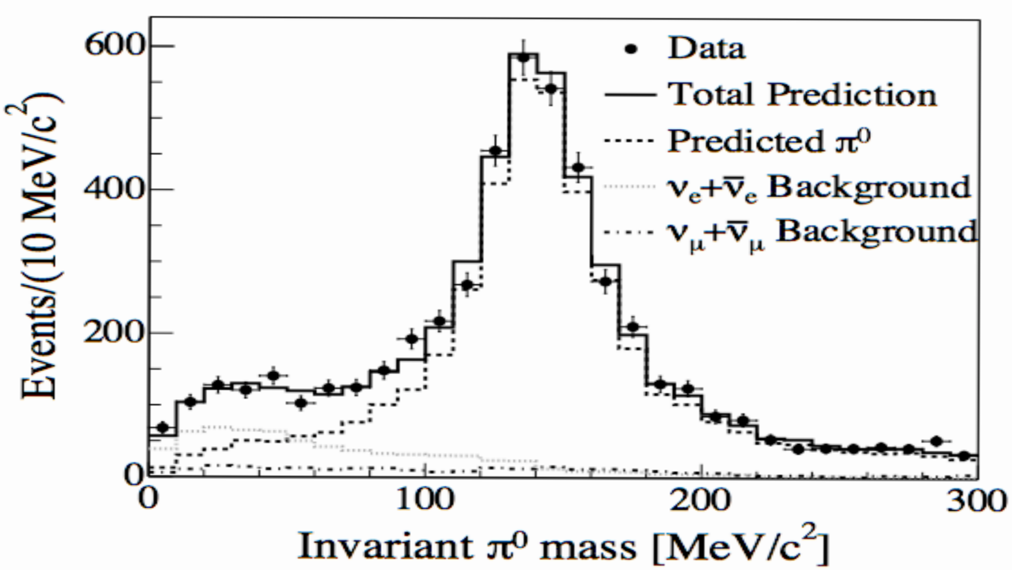
Fermilab Neutrino Beams



ν_e CCQE and π^0 samples from NuMI

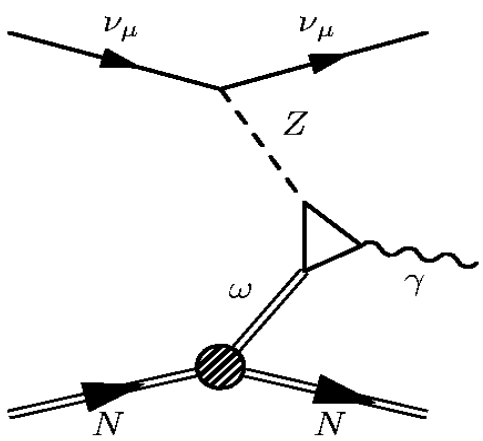


Parent information



Is there a physics explanation for Low E excess?

- Anomaly Mediated Neutrino-Photon Interactions at Finite Baryon Density (arXiv:0708.1281: Jeffrey A. Harvey, Christopher T. Hill, Richard J. Hill)



- CP-Violation 3+2 Model: Maltoni & Schwetz, arXiv:0705.0107

- Extra Dimensions 3+1 Model: Pas, Pakvasa, & Weiler, Phys. Rev. D72 (2005) 095017

- CPT Violation 3+1 Model: Barger, Marfatia, & Whisnant, Phys. Lett. B576 (2003) 303

- New Light Gauge Boson: Nelson & Walsh, arXiv:0711.1363